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Mesoscale heavy snowfall

Measuring ozone for 64 years

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A heavy snowfall within a mesoscale convergence zone

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SCIENCE & TECHNOLOGY

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Summary

The localized heavy snowfall over central southern England on the night of 18/19 March 1987 is investigated using mesoscale-model output and satellite and radar imagery. Factual and conjectural reasoning is employed to propose a conceptual model of the event.

1. Introduction

On the night of 18/19 March 1987, heavy snow — up to 30 cm in places — fell in a narrow band from Gwent in Wales to west Hampshire (Fig. 1). It caused considerable disruption to power supplies and road traffic. Satellite and radar images showed that the snow surprisingly fell a few hundred kilometres east of an initially conspicuous, well-developed comma cloud that moved south-east in a decaying state across Cornwall, and did not fall from cloud that developed, as is more usual, along the tail of the comma.

This case-study shows how images from satellites and radar, together with diagnostics from the mesoscale and fine-mesh models may be used to alert the forecaster to this type of development and to help understand the main physical and dynamical processes at work.

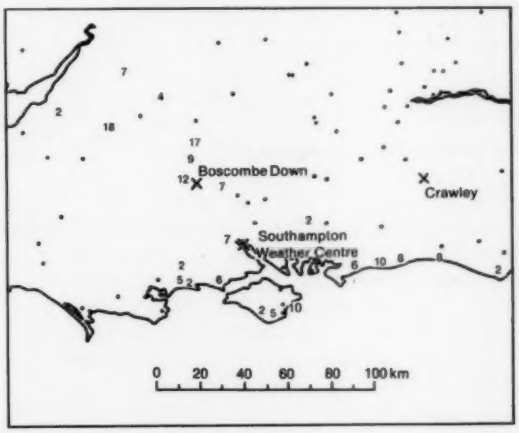
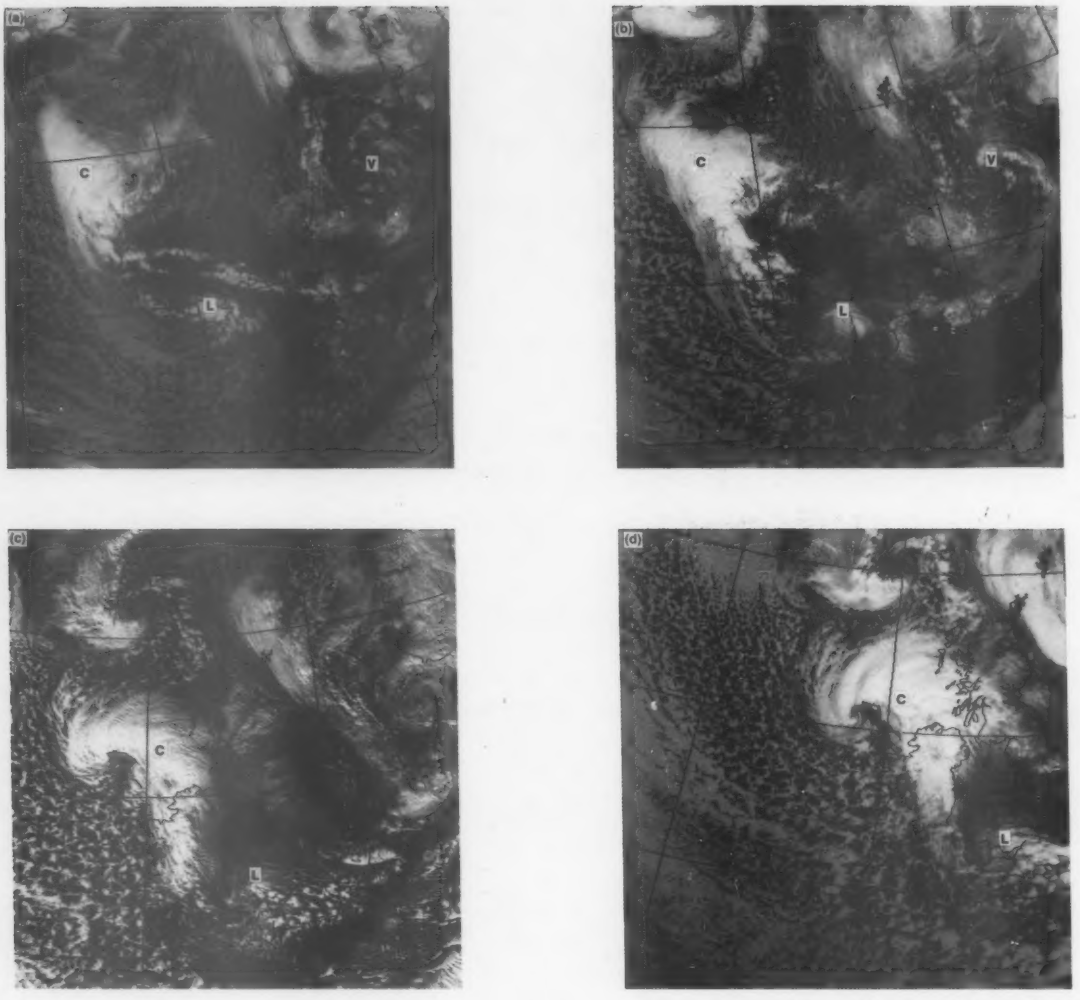


Figure 1. Snow depths (cm) over southern England at 0900 UTC on 19 March 1987 (dots are places with no snow). Southampton Weather Centre and Boscombe Down are stations whose weather sequence is shown in Fig. 8, and a Crawley radiosonde ascent is shown in Fig. 10.

2. Synoptic discussion

A deep, mature vortex was located over the northern North Sea under the cloud spiral, V, shown in the first of a sequence of NOAA-9 satellite infra-red images (Fig. 2(a)) at 0415 UTC on 18 March. Cold, unstable north-westerly winds (depicted by the cumuliform clouds on the image) prevailed over the north-east



Photographs by courtesy of University of Dundee

Figure 2. NOAA satellite infra-red images at (a) 0415, (b) 0820, (c) 1409, and (d) 1551 UTC on 18 March 1987, showing a mature vortex, V, over the northern North Sea, an area of cloud, C, that developed into a comma and an area of enhanced convection, L. C and L moved south-eastwards.

Atlantic and the United Kingdom on the western flank of V. Embedded in this airstream was an area of very cold cloud, C, situated between Iceland and Northern Ireland while a small vortex of enhanced convection, L, was evident downstream near north-west Ireland. C and L moved south-eastwards at 35–40 kn, C still to the west of the Hebrides, and L over eastern Ireland by 0820 UTC (Fig. 2(b)) although L was less prominent having crossed colder land. The visible image (not shown) reveals that C was bright and lumpy, i.e. deep and convective. By 1409 UTC (Fig. 2(c)), C had developed into a comma, with its 'tail' — interpreted as a belt of ascending air frequently giving precipitation — extending across Ireland. Meanwhile, L had moved into Wales and contained fresh convective cells formed topographically and by diurnal heating of the land. The curvature of the clouds still indicated the presence of a small vortex over South Wales. Both systems continued moving south-eastwards, the tail of C extending to south-west England by 1551 UTC (Fig. 2(d)). L was over the Severn Estuary having decelerated to about 20 kn and still showing signs of a vortex. The speed of the centre of C was now about 35 kn; at this velocity it would be close to south-west England by midnight, with its tail lying a little further east.

C was situated in a diffluent region just ahead of a well-defined upper trough (Fig. 3(a)) and was collocated with a large area of ascent shown in the fine-mesh

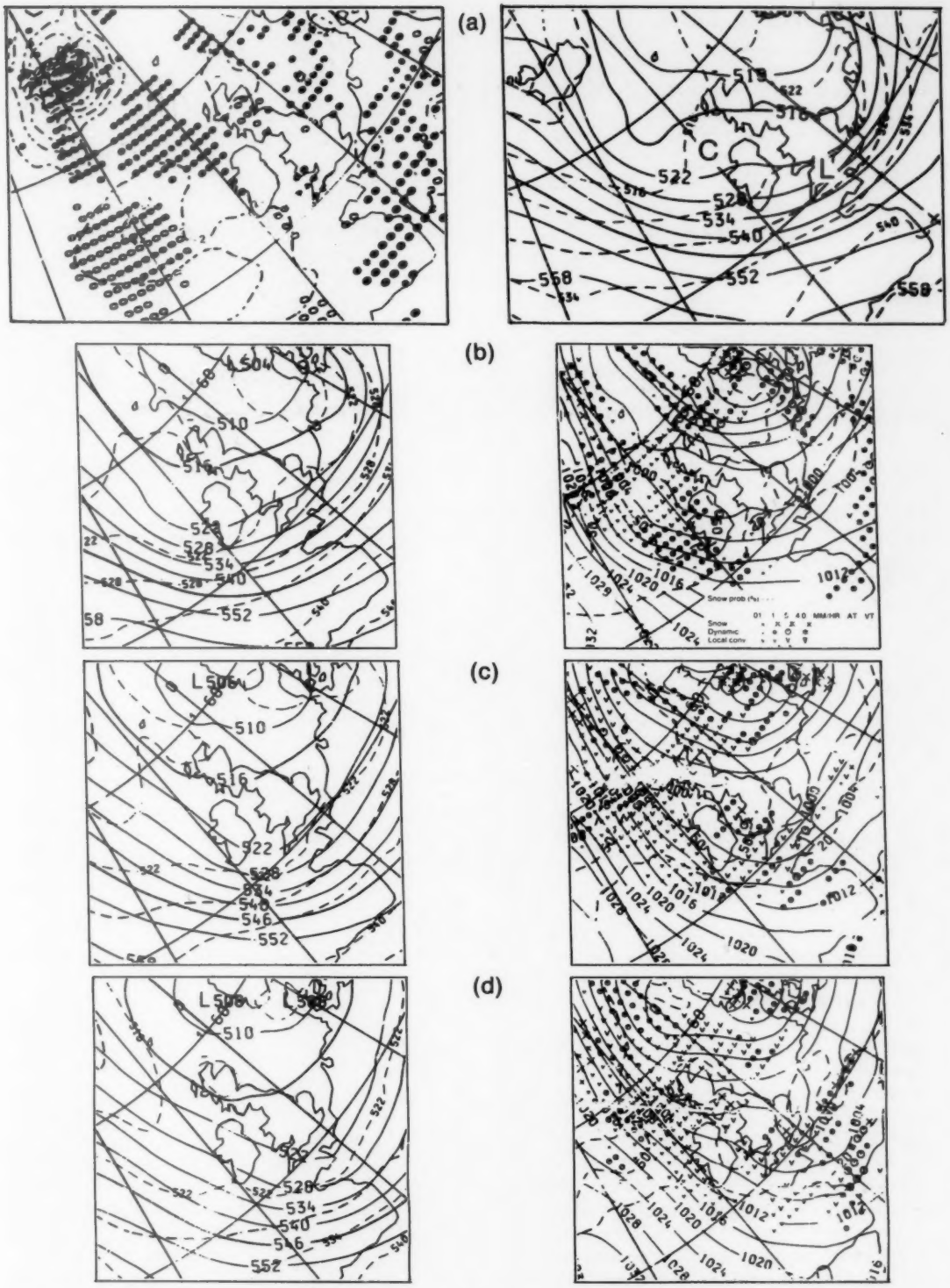


Figure 3. Fine-mesh model output on 18 March 1987 (a) analysis for 1200 UTC (open symbols — descending, closed symbols — ascending, dash-dot line — thermal advection cooling between 850 and 500 mb), C and L as in Fig. 2, (b) forecast for 1800 UTC, (c) forecast for 0001 UTC on 19 March, and (d) forecast for 0600 UTC on 19 March.

model's analysis. (It is worth noting that without satellite images, the scale and structure of C would not have been determined until it had moved into Ireland.) Another smaller region of ascent was situated over the south-west of the United Kingdom and was collocated with L. In the absence of any warm air advection, both regions of ascent resulted from advection of positive vorticity (PVA).

The fine-mesh model forecast the upper trough to move south-eastwards at about 40 kn (Figs 3(b)–3(d)) taking the surface trough and any 'dynamical' precipitation south-eastwards from Ireland across southern England to northern France during the night. Indeed, snow was forecast at two grid-points over southern England at 0600 UTC on the 19th, close to the surface trough and east of the extrapolated position of the comma system. The analysis over the British Isles for 1800 UTC shows that the centre of the circulation associated with the comma approached north-west Ireland (Fig. 4) but there was also a surface trough with significant falls of pressure ahead of it which had moved south-eastwards to central southern England and which was associated with L.

The following sections showed how the fine-mesh model's forecast of precipitation may be fine-tuned using satellite and radar images together with mesoscale model guidance so that the areas most prone to mesoscale areas of precipitation — which in this case may be persistent (because of the light upper winds) and may fall as snow — can be identified and the dynamical processes explained.

3. Mesoscale-model forecast

Fig. 5 shows the dynamic and convective precipitation predicted by the mesoscale model for 2100, 0000 and 0300 UTC using a re-run of the 1800 UTC operational run with the comma reinitialized 250 km further west, to north-west Ireland. The precipitation patterns were almost identical to the original operational run, hinting that the comma system itself was not a primary factor in the development of the snow event. At 2100 UTC, an area of rain and snow was forecast to extend from the Bristol Channel northwards through Wales, curving round towards Northern Ireland. This pattern conformed with the shape of the comma (Figs 2(c) and 2(d)) and was forecast to move south-eastwards, being a natural

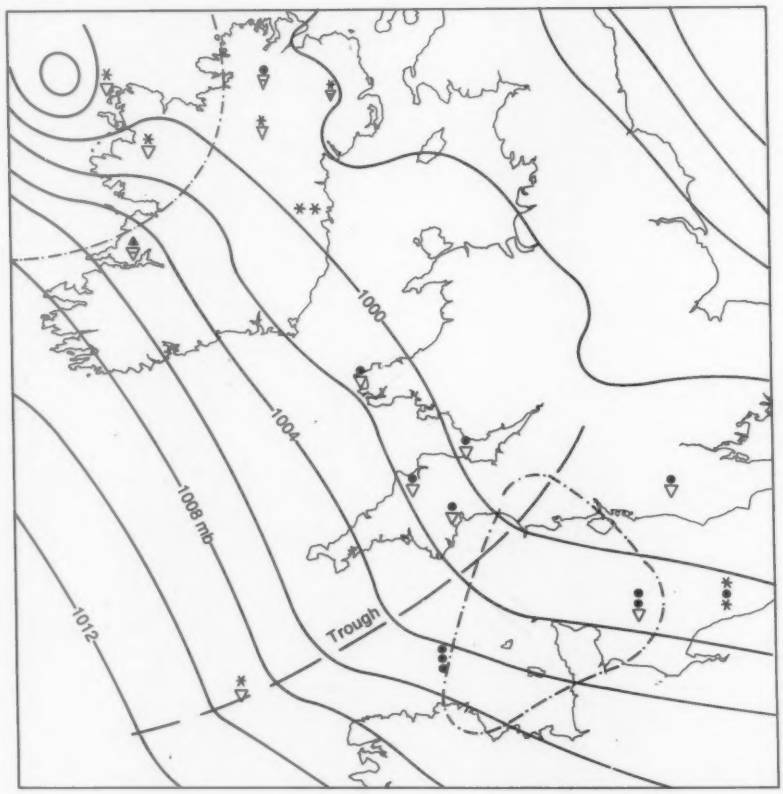


Figure 4. Mean-sea-level pressure analysis for 1800 UTC on 18 March, showing a developing trough over southern England and the circulation associated with the comma cloud approaching north-west Ireland. Places reporting significant present weather are shown, using conventional symbols. The areas enclosed by the dot-dash lines are where pressure is falling by ≥ 1 mb $3h^{-1}$.

evolution of existing features. However, over central southern England, to the east of the comma tail, the model developed a separate area of rain and snow, perhaps related to the earlier decelerating vortex L. This precipitation was forecast to move slowly east, turning increasingly to snow (Figs 5(b) and 5(c)). Shower symbols were present within the areas of dynamic rain, suggesting release of potential instability. Showers were also forecast, especially over the sea and the windward coasts.

To what extent did the features on the satellite and radar images support the mesoscale-model guidance in the forecast period?

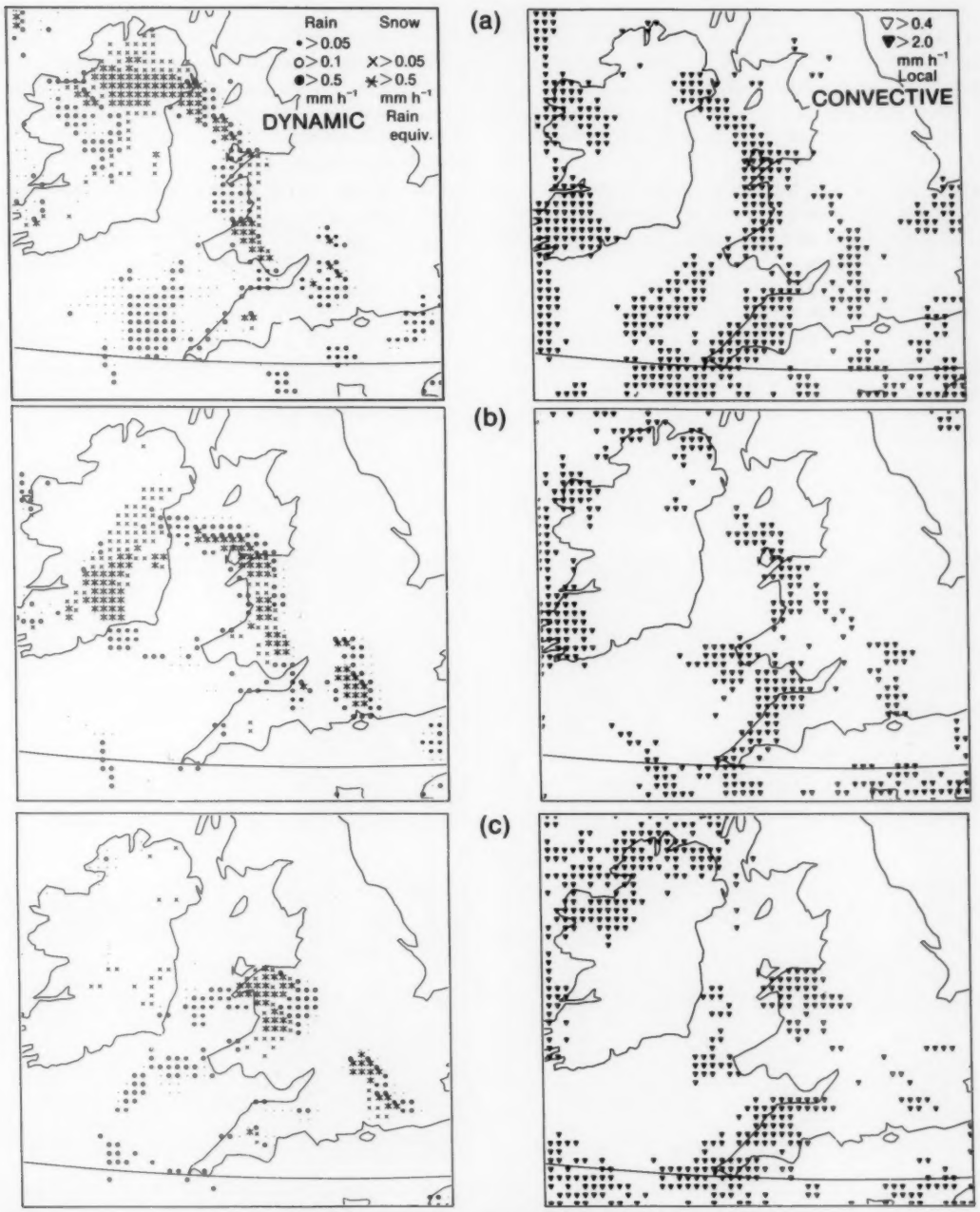


Figure 5. Mesoscale-model forecasts of precipitation, based on a data time of 1800 UTC on 18 March 1987 for (a) 2100 UTC on 18 March, (b) 0001 UTC on 19 March, and (c) 0300 UTC on 19 March. See key for explanation of symbols.

4. Comparison between mesoscale-model forecast with satellite and radar images

False colour satellite images from Meteosat were used to follow the evolution more closely near the United Kingdom during the evening of the 18th. At 1900 UTC (Fig. 6(a)) the tail of the comma cloud extended south-east from western Ireland towards South Wales, while relatively warm convective cloud tops (with a sharp northern temperature gradient) associated with L in Fig. 2 covered the southern United Kingdom. After 1900 UTC the cloud tops in the tail warmed, but a new area of cloud grew just east of the tail over central southern England (Fig. 6(b)), shown more clearly by observations from the UK weather radar network (Figs 7(a) and 7(b)). Precipitation from the tail fell in a band over south-west England and west Wales while the new cloud area was associated with another band of precipitation orientated in the same direction to the east. This pattern supported the mesoscale-model forecast (Fig. 5(a)) except that the model developed the new band a little too far east.

By 0130 UTC on 19 March (Fig. 6(c)) the depth and area of cloud over central southern England had grown considerably and produced the heaviest precipitation (Fig. 7(c)) which fell on or just to the west of the surface trough shown on Fig. 4. Other features of interest were the sharp south-western edge of the precipitation band (not an idiosyncrasy of the radar data) and the vortex-shaped echo over south-west England associated with the south-eastward moving comma. The mesoscale-model forecast over central southern England for midnight (Fig. 5(b)) compared favourably with the observed pattern except that the forecast precipitation band was orientated more north–south. The band lasted until early on the 19th (Figs 6(d) and 7(d)) as predicted by the mesoscale model.

Examination of the higher resolution radar data from Chenies, to the north-west of London, shows that the band of precipitation consisted of heavy showers which were effectively stationary for periods exceeding one hour, accounting for considerable accumulation of snow in some parts. Fig. 8 shows the hourly observations from Boscombe Down and Southampton Weather Centre, both situated within the band, where continuous snow, often moderate or heavy, was reported between about 0000 and 0500 UTC. Further details about the distribution of the snowfall are given in Pike (1989).

The mesoscale model has captured the development and persistence of the band sufficiently well for a conceptual model of the principal airflows to be deduced from appropriate diagnostics.

5. Conceptual model

Several factors, combining to produce the snow event, now assist in the construction of a conceptual model. They fall into 'factual' and 'conjectural' categories.

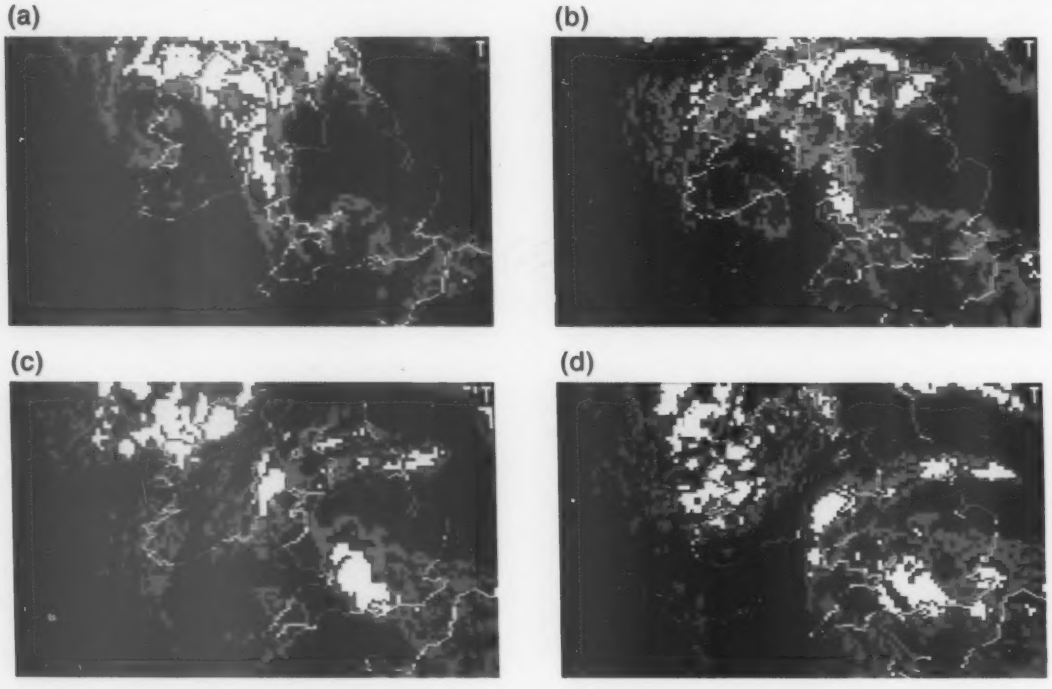


Figure 6. False colour Meteosat infra-red images showing the south-eastward movement and warming of the cloud associated with the comma, centred initially west of Ireland, and the growth of the cloud east of the comma tail over central southern England for (a) 1900 UTC on 18 March 1987, (b) 2200 UTC on 18 March, (c) 0130 UTC on 19 March, and (d) 0400 UTC 19 March. White denotes coldest tops (< −40 °C). The other colours are interpreted as follows: dark red, < −30 °C; pink, < −20 °C; dark blue, < −10 °C; black, > −10 °C.

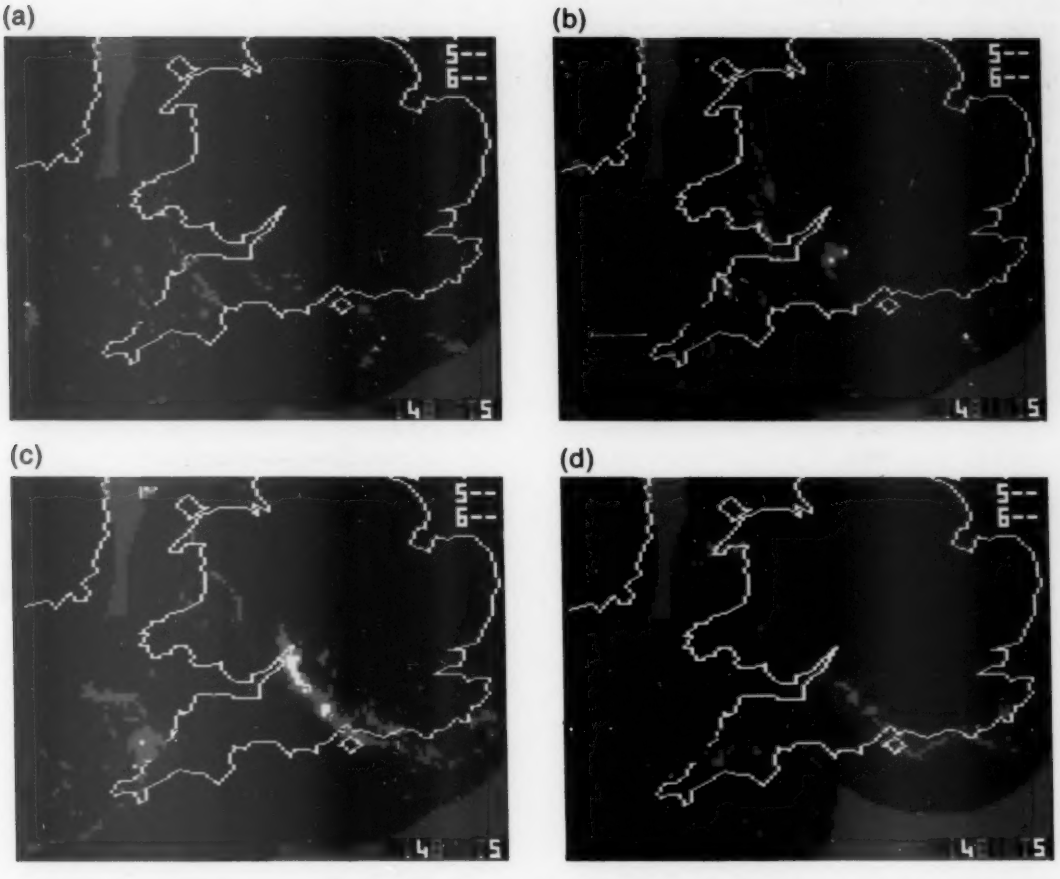


Figure 7. Precipitation shown by the UK weather radar network at (a) 1900 UTC on 18 March, (b) 2200 UTC on 18 March, (c) 0100 UTC on 19 March, and (d) 0400 UTC on 19 March. Equivalent rainfall rates are as follows: dark blue, < 1 mm h^{-1}; green, 1–4 mm h^{-1}; yellow, > 4 mm h^{-1}.

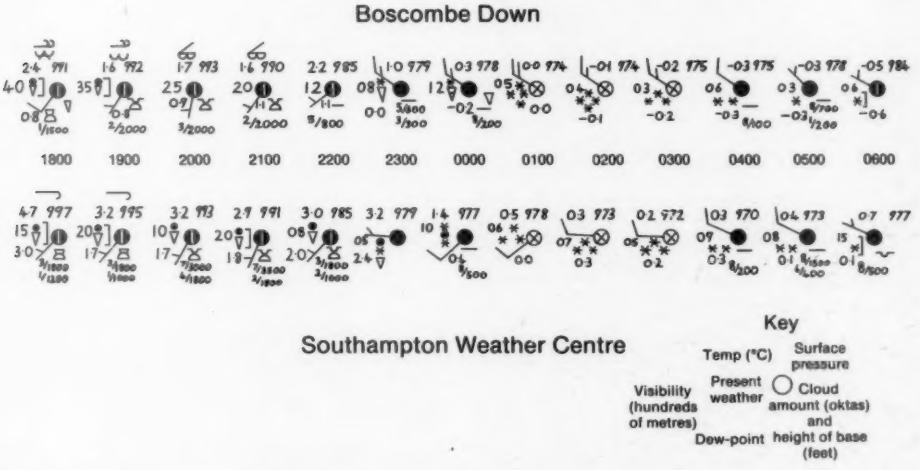


Figure 8. Hourly (UTC) surface weather observations, using conventional symbols, during night of 18/19 March 1987 at Boscombe Down and Southampton Weather Centre, whose locations are shown in Fig. 1. See key for explanation.

5.1 Factual information

(a) The limits of the snow band were well defined from the imagery and the observational network (see Figs 1 and 7).

(b) The western edge was sharp, suggesting significant undercutting of cold air from the west.

(c) Strong westerly winds on the southern flank of the comma system extended across the snow area during the event and moved away southwards, as shown by the sequence of observations at Boscombe Down in Fig. 8. (Southampton Weather Centre is more sheltered.)

(d) An upper trough crossed the south-west peninsula at about 40 kn (Fig. 9) and a little slower over the snow area. It was ill-defined further north. Its axis lay over southern England at 0400 UTC, when the snow was dying out in the north-west of the band, and from Cherbourg to Brest at 0600 UTC, when the snow had ceased over central southern England (Fig. 8).

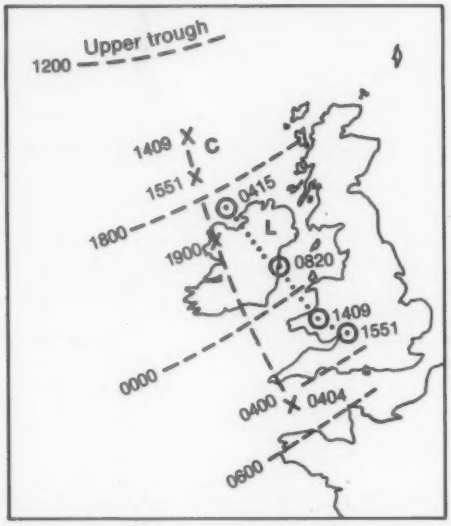


Figure 9. Tracks of cloud systems C and L (shown in Fig. 2) and upper trough axis, from 1200 UTC on 18 March to 0600 UTC on 19 March 1987.

(e) Winds below 600 mb at Crawley became easterly at midnight on the 19th (Fig. 10). There was no easterly component before or after this time. The easterly wind was supported by wind profiles derived from the mesoscale model from spot locations within and just east of the snow area.

(f) A cross-section from south-west England to the Thames Estuary (Fig. 11(a)), derived from the mesoscale-model forecast, reveals a tongue of high wet-bulb potential temperature (WBPT) over the eastern portion at about 600 m above the surface. The dynamical precipitation shown in Fig. 5 was forecast to be close to the western edge of this tongue.

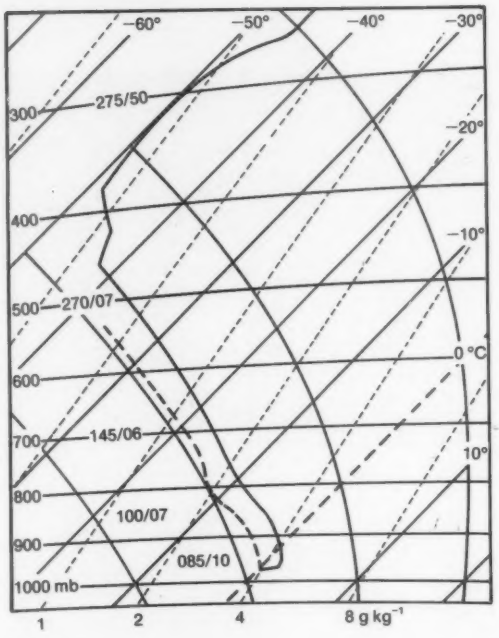


Figure 10. Radiosonde sounding at Crawley (see Fig. 1) at 0001 UTC on 19 March 1987.

(g) The ascent at Crawley for midnight on 19 March (Fig. 10) showed potential instability. Since the higher WBPT layer was centred at 600 m, only about 200 m (20 mb) of lifting would have sufficed to release this instability.

(h) Fig. 12 shows an isentropic analysis of air on the 7 °C surface (i.e. representing the warm tongue) relative to a 'system' speed of 300° 12 kn. This system speed was chosen from the model's forecast of the 700 mb wind on the western edge of the area of high WBPT over southern England during the early stages of the precipitation event. This corresponds to the velocity of the precipitation band. The relative flow chart for 2100 UTC (Fig. 12(a)) shows a circulation centre and zone of convergence just east of the Bristol Channel. To the east, the weak ascent is probably sufficient (see (g)) to release the potential instability. Later on, at midnight and 0300 UTC (Figs 12(b) and 12(c)), there is more rapid ascent up the steepest slope of the potential temperature surfaces; it is associated with the main area of precipitation in Figs 5(b) and 5(c).

5.2 Conjectural factors

(a) A 'cold dome' of WBPT, where the precipitation fell (see Fig. 11(b)), was probably due to heat being extracted from the air by melting snow.

(b) A cross-section of the winds (Fig. 13) at 2100 and midnight UTC shows the westerly winds advecting air of low WBPT towards the slower-moving warm tongue and creating a convergence zone over central

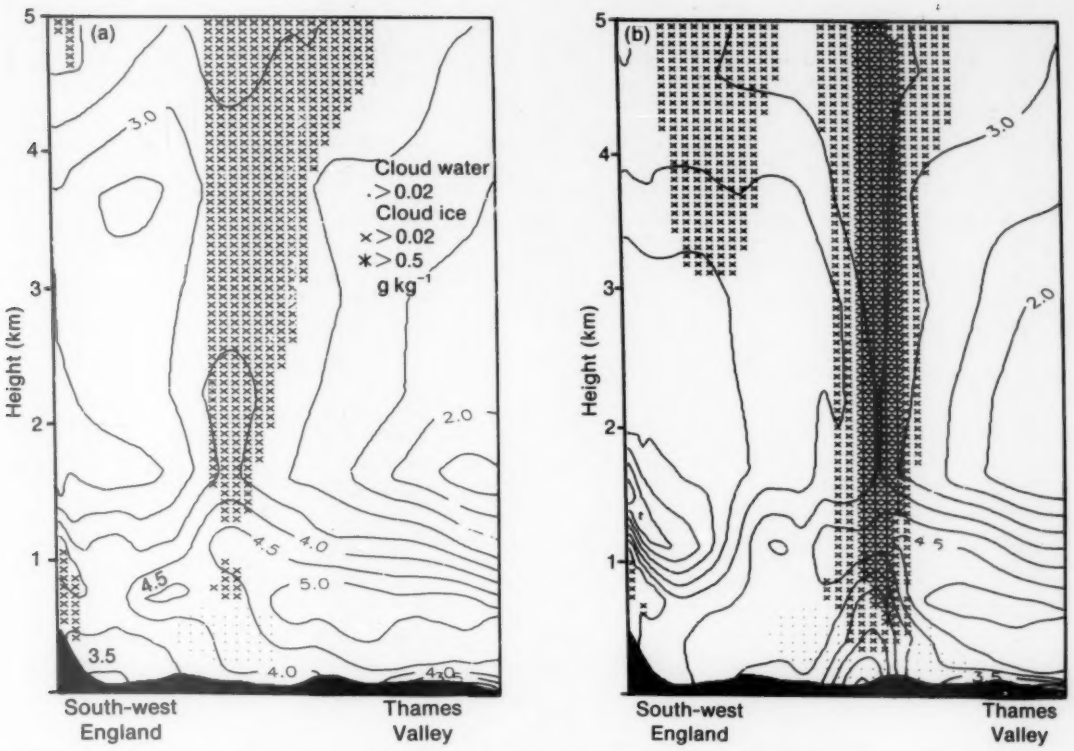


Figure 11. Cross-section of wet-bulb potential temperature (°C) and cloud at (a) 2100 UTC on 18 March, and (b) 0001 UTC on 19 March 1987 (from the mesoscale-model forecast at 1800 UTC). Note the warm tongue of air in the bottom right-hand corner and the cold dome becoming established near the ground at 0001 UTC due probably to latent heat being extracted from the air as the snow melts. Symbols are explained in the key.

southern England. Any undercutting of the potentially unstable flow by the cooler westerlies on the southern side of the comma system may have produced enough lifting to release the instability, the effect becoming self-perpetuating due to the generation of the 'cold dome', thus contributing towards the persistence of the snowfall.

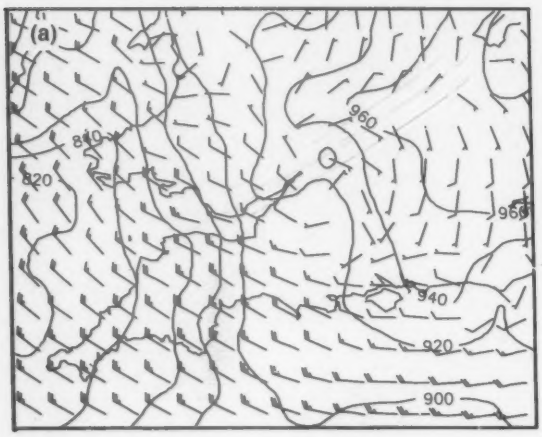
(c) Although the air mass was equally inherently unstable over much of southern England and the layer of high WBPT extended over the whole of south-east England, it is significant that the area covered by the snow was very limited. The main factors occurring over the snow area and not further east were the undercutting westerlies and probably a PVA maximum ahead of the upper trough. Furthermore, the snow ceased when the south-eastward moving upper trough axis crossed the area and, almost coincidentally, the undercutting westerlies were transferred to the south, as the comma system moved away.

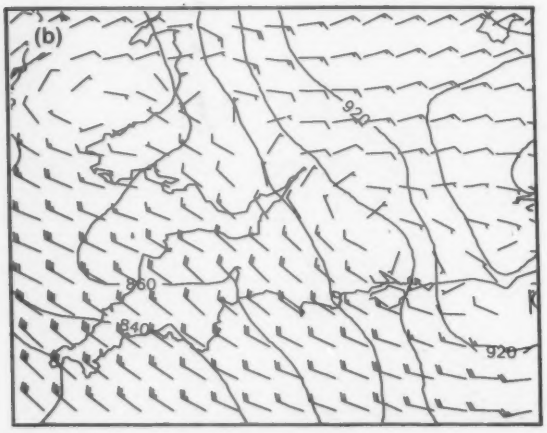
Using the imagery from Meteosat and the radar network and the isentropic analysis from the mesoscale model, a conceptual model has been constructed (Fig. 14).

Fig. 14(a) shows principal airflows at 2200 UTC. With the southern end of the old comma tail then decaying, the westerlies near the surface extended into central southern England, undercutting a new warm conveyor belt formed as the easterly flow rose along the inclined 7 °C potential temperature surface (Fig. 12). By 0130 UTC (Fig. 14(b)), the old comma tail had decayed over much of England and Wales, but the new ascending warm conveyor belt overriding the colder air was now well established over central southern England.

These ideas are supported by the features on the NOAA-9 satellite picture for 0404 UTC on 19 March (Fig. 15). It shows the old comma between south-west England and Brest and the ascending (cloudy) warm conveyor belt over central southern England, with its well-marked western edge.

The ascending warm conveyor belt is well analysed by the fine-mesh model at midnight on the 19th showing the tongue of high 850 mb WBPT extending from northern France into southern England (Fig. 16(a)) and air ascending within it (Fig. 16(b)) containing low and medium cloud (Fig. 16(c)). These patterns suggest that the warm conveyor belt constituted part of a larger scale dynamical circulation even though a mesoscale explan-





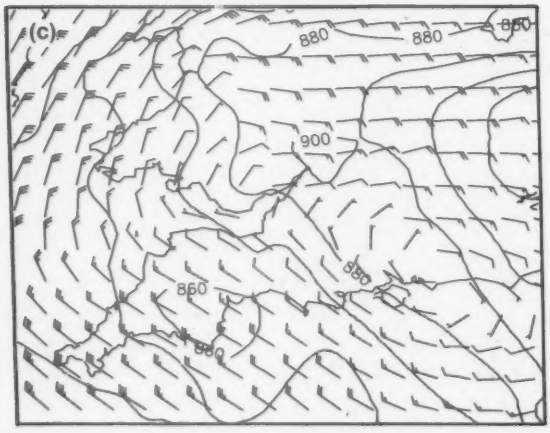
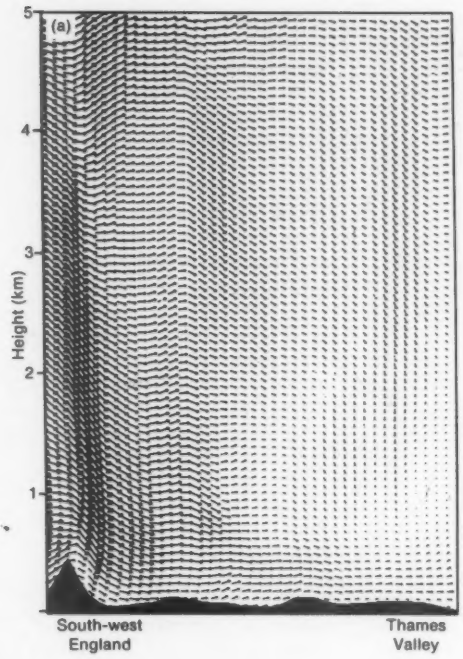


Figure 12. Relative-flow, isentropic analysis (from the mesoscale-model forecasts) along the 7 °C potential temperature surface (mb) at (a) 2100 UTC on 18 March 1987, (b) 0001 UTC on 19 March 1987, and (c) 0300 UTC on 19 March 1987. Compare with the precipitation forecast at the same times shown in Fig. 5.



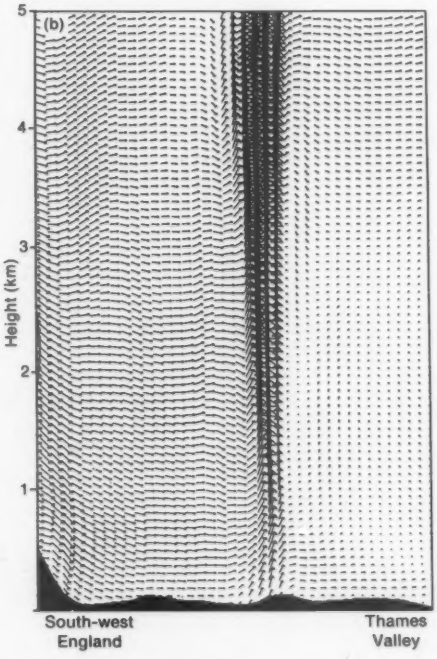


Figure 13. Cross-section of winds from the mesoscale-model forecast along the same line as shown in Fig. 11 at (a) 2100 UTC on 18 March 1987, and (b) 0001 UTC on 19 March 1987.

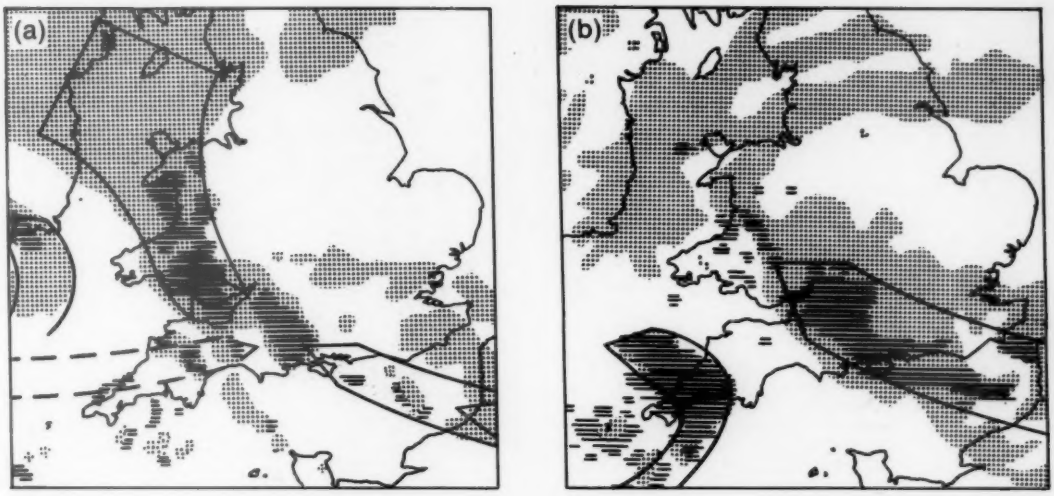


Figure 14. Conceptual model of principal airflows at (a) 2200 UTC on 18 March 1987, and (b) 0130 UTC on 19 March 1987. Cloud tops < -20 °C stippled, precipitation, as detected by the radar network, striated.

Photograph by courtesy of University of Dundee

Figure 15. NOAA-9 satellite infra-red image at 0404 UTC on 19 March 1987, showing the comma cloud, C, between south-west England and Brest, and the sharp western edge, W, of the cloud over central southern England.

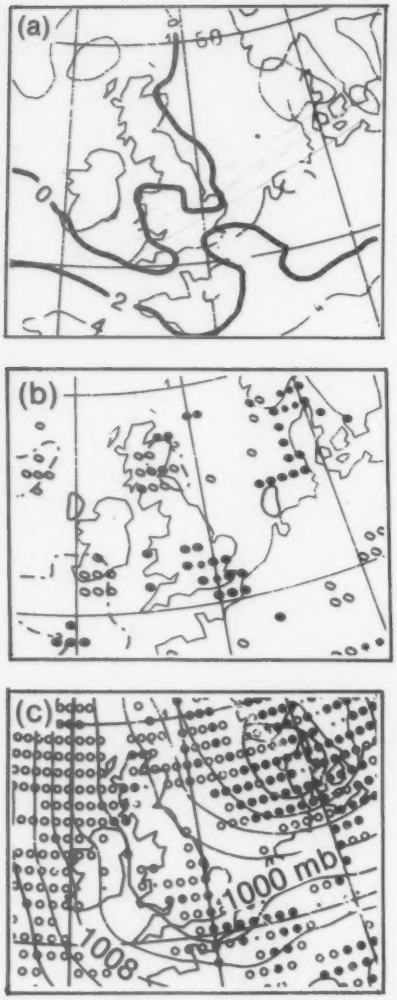


Figure 16. Fine-mesh model analysis at 0001 UTC on 19 March 1987 of (a) 850 mb wet-bulb potential temperature (°C), (b) vertical velocity and thermal advection (symbols as in Fig. 3(a)), and (c) medium cloud (open circles), low cloud (dots) and mean-sea-level pressure at 4 mb intervals.

ation might seem attractive on the basis of the area and duration of precipitation.

6. Conclusion

This case shows how forecasts from the mesoscale model and frequent monitoring of the satellite and radar images can enable the forecaster to justify playing down the likely impact of an initially conspicuous feature (the comma) in favour of a probable new important mesoscale development (i.e. the band of heavy snow) that does not conform with conventional ideas (i.e. the development of precipitation along an existing comma tail). It also showed how the diagnostics from the mesoscale model, supported by those from the fine-mesh model, can enhance the understanding of the main physical and dynamical processes at work.

The eventual arrival of faster Information Technology Systems such as the Outstation Display System (ODS), AUTOSAT 2 and the weather information system and network (WIS/WIN) will provide outstation forecasters with more imagery and a wider range of model diagnostics such as isentropic analysis (related to the speed of a specific system) to help with their diagnosis and prognosis.

Acknowledgements

The authors wish to thank M.V. Young for helpful discussions and L. Rowley for processing the model products.

Reference

Pike, W.S., 1989: The heavy localised snowfall over central southern England overnight 18th–19th March 1987. *J Meteorol UK*, **14**, 76–82.

Correction

Meteorological Magazine, December 1989, p. 265, Summary. Mr R.A. Murray has pointed out that the winter of 1988/89 was not particularly dry. The author's intention was to stress the exceptional combination of mildness and dryness.

551.508.952

Sixty-four years of regular ozone measurements

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Summary

A brief account is given of the development of the Dobson ozone spectrophotometer which has been used for over 60 years to make world-wide measurements of atmospheric ozone amounts. These observations define the normal behaviour of ozone against which recent reductions – the Antarctic ozone hole – can be compared.

1. Introduction

Regular daily ozone measurements have been made since the year 1926, but while one instrument type has dominated the measurements for nearly the whole of this period, the reasons for making the measurements have changed over the years. Researchers today concerned with the long-term changes in the atmospheric ozone column, would be very interested in the whole of this extensive data set, but nobody at the time imagined our present day interests, and only the data from Arosa in Switzerland have been retained and corrected to form as nearly as possible a consistent data set. It must be recognized, though, that early data are likely to contain systematic errors which are difficult to estimate.

In 1879 Cornu suggested that the sharp ultraviolet cut-off in the solar spectrum might be due to ozone, and in the following year Hartley measured the absorption band which bears his name. Visible light in the incoming solar spectrum is much more intense than ultraviolet, so scattered light is always a problem in measuring ozone, but in 1920 Fabry and Buisson used a double photographic spectrograph and obtained a value 0.3 cm of pure ozone at standard temperature and pressure (i.e. 300 milli atm. cm) for the equivalent vertical ozone column. This is the sort of value to be expected in early summer when they made their measurements.

In 1921 Lindemann (later Lord Cherwell) suggested a way of determining the density of the upper atmosphere from the visible brightness, speed and height of meteor trails. The results showed densities orders of magnitude greater than expected in an isothermal atmosphere at the temperatures recently measured in the lower stratosphere. Lindemann saw that absorption of solar radiation by ozone could account for the rise in temperature with height he had to postulate. It was also known that the lower stratosphere was colder over a surface anticyclone than over a surface 'low'. This led to the speculation that these surface features might be caused by variations in the ozone column. This was the motivation for the first regular ozone measurements (Dobson 1966).

2. Theory of ozone-column measurements

The basic theory of diffential absorption is the same for all ozone-column measurements. It is reproduced here with specific reference to the notation used for the Dobson spectrophotometer so that the significance of improvements can be seen. The slit widths used by Dobson were such that all light within the pass-band can be assumed to have the same absorption coefficient, so Beer's law can be used in the form

$$\log_{10}(I_\lambda/I_{\lambda'}) = \log_{10}(I_{o\lambda}/I_{o\lambda'}) - \mu x(\alpha-\alpha') - $$

$$- m(\beta-\beta') - \sec Z(\delta-\delta')$$

where x is the ozone-column amount; I_λ, $I_{\lambda'}$ are the measured intensities, and $I_{o\lambda}$, $I_{o\lambda'}$ the intensities outside the atmosphere; α, α' the absorption coefficients; β, β' the Rayleigh scattering coefficients; δ, δ' the aerosol scattering functions, all at wavelengths λ, λ'; μ is the secant of the zenith solar angle at the height of the ozone layer, m the Bemporad air-mass function and Z the solar zenith angle at the surface (where most of the aerosol scattering is assumed to arise). The last three parameters can be calculated from the station coordinates and the time and date. Putting

$$A = (\alpha-\alpha'),\ B = (\beta-\beta'),\ N = -\log_{10}(I_\lambda, I_{\lambda'}),\ \text{and}$$

$$N_o = -\log_{10}(I_{o\lambda}, I_{o\lambda'}),$$

$$\text{then}\quad x = \{N-N_o) - B\,m - (\delta-\delta')\sec Z\}/\mu A. \qquad (1)$$

Equation (1) can be rearranged to be

$$N/\mu - B\,m/\mu = Ax + N_o/\mu$$

so that N_o can be evaluated by means of a Langley plot, i.e. a plot of $N/\mu - Bm/\mu$ against $1/\mu$ under conditions where x can be assumed constant and the aerosol scattering negligible.

If two wavelengths designated A and D are used, equation (1) becomes

$$x = (N_A-N_{oA}-N_D+N_{oD})/\mu(A_A-A_D) -$$

$$- (B_A-B_D)m/\mu(A_A-A_D).$$

With the wavelengths designated *A* and *D* by Dobson, the second term amounts to 9 milli atm. cm for a station at mean sea level. The *B*-terms vary as λ^{-4}, the δ-terms vary significantly less rapidly, and except in unusual conditions can safely be assumed negligible.

3. Apparatus developed by Dobson

G.M.B. Dobson designed the first ozone spectrograph for routine use. To keep the apparatus simple he used a single Féry prism which combines a prism and a concave mirror in a single piece of quartz. Thus there is only one air-dielectric interface, though it is traversed twice, and this minimizes the amount of scattered light. Further reduction in visible light was achieved by a filter comprising a fused silica cell filled with chlorine, bromine and (it transpired) chlorine bromide. After some time spent refining the process of developing the photographic plates and measuring their density, reproducible results were obtained. It was found that there were significant day-to-day variations correlated with surface pressure variations and (surprisingly at the time) an annual variation with a maximum in spring.

In 1926, five more photographic spectrographs were made by Dobson and sent to Valentia (Ireland), Lerwick (Shetland), Arosa (Switzerland), Abiska (Sweden) and Lindenberg (Germany). The plates were sent back to Oxford for processing. If any practical use was going to be made of ozone measurements for weather forecasting, the delay caused by posting and batch processing the plates was unacceptable. The hope that ozone measurements could help weather forecasts took a long time to die, and total ozone column measurements were made at Lerwick and some mainland stations during the 1939–45 war with the results radioed to Oxford in cipher. This was the incentive for the design of the first photoelectric spectrophotometer.

Dobson built his first photo-electric spectrophotometer in 1926. It was in regular use until his death in 1976, and its optical design was reproduced in the first commercial instrument designated No. 2 built by R. & J. Beck in 1930. This instrument, shown in Fig. 1, was loaned to the Meteorological Office around 1960 and later donated by Professor Dobson's widow. It is still in daily use, formerly at the Office's experimental site at Beaufort Park, near Bracknell, and since autumn 1989 at Camborne, where it is less subject to disturbance by atmospheric pollution. It is a double spectrophotometer with quartz prisms as the dispersing element (Fig. 2). Light passing through the two wavelength selecting slits S_2 and S_2 is recombined by the second optical train

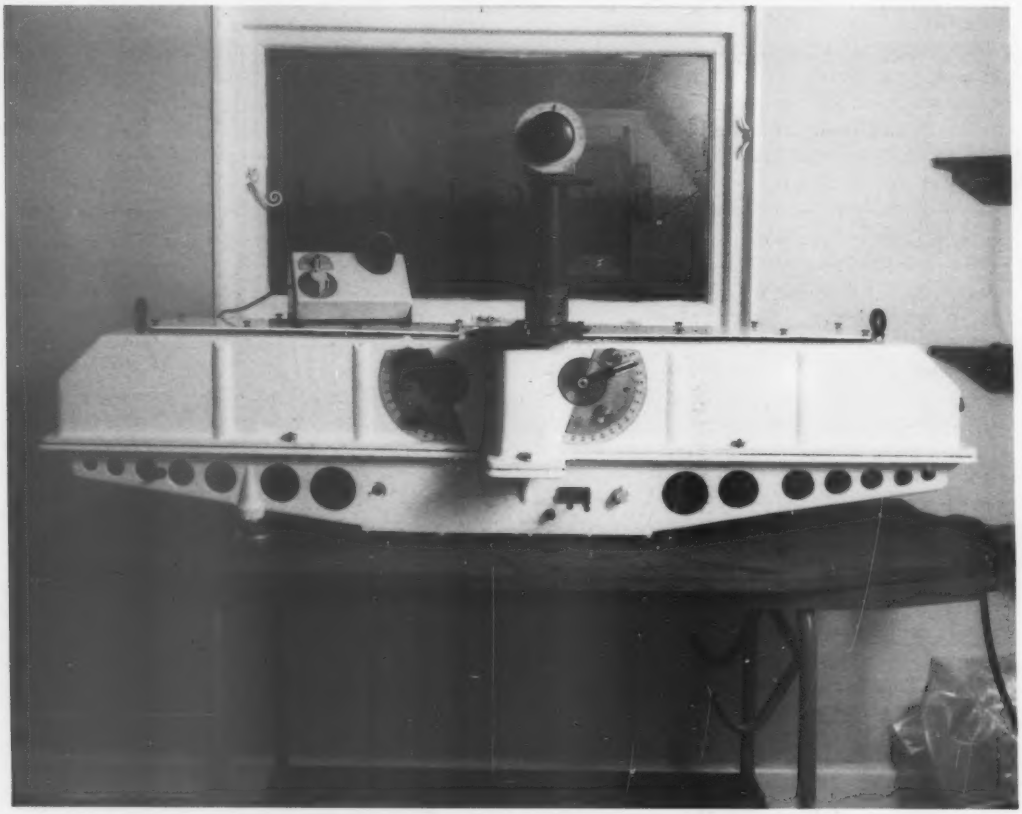

Figure 1. View of the Dobson ozone spectrophotometer.

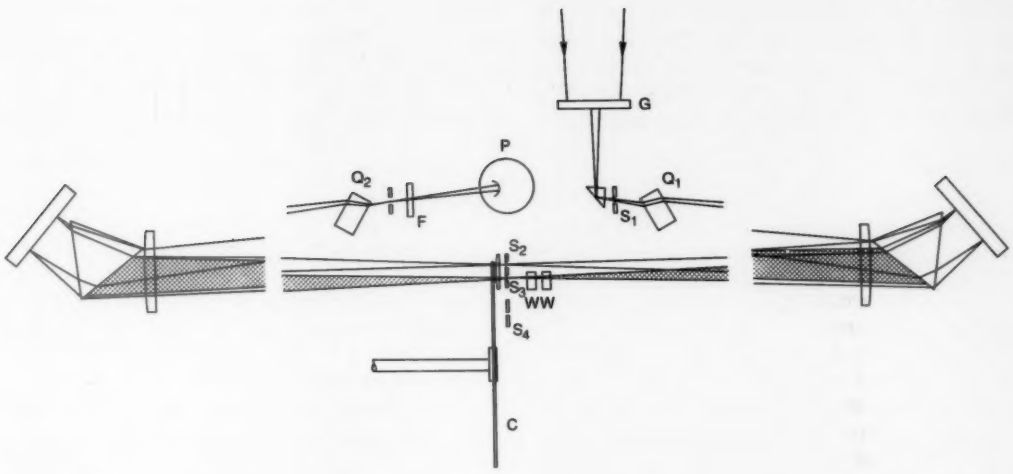

Figure 2. Optical system of the Dobson ozone spectrophotometer. C is the rotating chopper disc which exposes S_2 and S_3 alternately; F is the glass ultraviolet filter; G is the ground quartz plate used for normal direct Sun measurements; P is the photomultiplier; Q_1 and Q_2 are the quartz plates which are tilted to select the required wavelength pairs; S_1 is the input slit, which is curved concave upwards; S_2 and S_3 are the wavelength determining slits; S_4 is now only used in conjunction with an auxiliary lamp during wedge calibration; Ws are the two optical wedges.

which is a mirror image of the first. Light at wavelength λ' passing through S_3 is attenuated by a pair of optical wedges moving in opposition and actuated by a dial. A rotating disc chopper allows light from first one slit then the other to reach the detector. The operator rotates the dial until the two detector currents are equal, when there is no alternating-current component in the amplifier output, and notes the dial reading R. The dial needs to be calibrated to relate the reading to the value of N in the above theory. For the accuracy demanded today, the wedges need to be re-calibrated about every 4 years.

The first detectors used were sodium photocells. It was not until 1945 that they were replaced by photomultipliers, and this made it possible to use a wider range of wavelengths. Dobson (1957) designated four wavelength pairs and it was soon appreciated that using two pairs had the advantage noted in the theory above. Earlier observations were derived from measurements made on the C-wavelength pair only, and are subject to greater errors due to aerosol scattering. If the input slit is illuminated by a source with a continuous spectrum the instrument will assign to the source a certain N-value for each wavelength. This value drifts slowly and it has become customary to perform standard lamp-tests every month and to adjust the $R-N$ tables to keep the lamp N-value constant. A second lamp is kept at each station which is used once a year. Earlier filament lamps lacked stability and were prone to premature failure. Quartz-halogen lamps introduced in the mid 1960s were a great improvement. A system using separate current and potential leads and a stabilized direct-current supply introduced by Dr W.D. Komhyr of NOAA was a further improvement. Used like this the two lamps normally agree well, implying it is the instrument which drifts. If standard lamps are exchanged between instruments, this might seem to be a method for transferring the additive constant N_o. In practice, making observations of the Sun with two instruments side-by-side yields results which differ slightly from those obtained by exchanging lamps, and for results of the highest accuracy there is no alternative to side-by-side comparison.

Dobson found conditions at Oxford unsatisfactory for producing Langley plots to determine N_o. He took his instrument to Arosa on a number of occasions, and after the international comparison of Dobson instruments at Belsk in 1974 it was resolved that the instrument No. 83 which had been calibrated at Mauna Loa (Hawaii) under conditions of low turbidity and small ozone variability should become the world standard. The calibration of most instruments is now traceable directly or indirectly to this instrument.

Dobson received a grant of £50 from the Royal Society to build No. 1, the instrument he himself made. R. & J. Beck charged £500 for No. 2, and a batch of instruments, made for the International Geophysical Year in 1957, were offered at a special price of £385. A recent batch of Dobson instruments are believed to have cost in the region of £35 000 each. This alone provides a strong incentive to find an alternative.

4. Other instruments

The USSR has made extensive use of filter instruments, the M83 patented in 1964 and the later improvement, the M124 patented in 1981. These have very much wider wavelength acceptance and therefore suffer from progressive hardening of the radiation as the ozone amount and/or path length increase. They also use only

one wavelength pair, and cannot secure the same freedom from errors caused by turbidity which can be obtained by using two wavelength pairs. An instrument based on narrow-band interference filters (each filter comprising two filters in cascade) was described by Basher and Matthews (1977), but suffered from long-term drift of the filters. The remaining contender is the Brewer instrument (Brewer 1973). This is a single-grating instrument which depends on recent advances in grating manufacturing techniques, together with absorption filters to remove long-wavelength radiation, to achieve an acceptable freedom from scattered light. It has five wavelength-selecting slits which are exposed in turn by a rotating chopper. One wavelength is chosen for the measurement of sulphur dioxide, and this makes it possible to correct the ozone readings on the occasions when this gas has accumulated under an inversion. The photomultiplier is used in a photon counting mode, so that after a common amplifier and discriminator the pulses are gated into five separate counters. There are thus no optical wedges, but a correction is needed at the higher count-rates for the finite dead-time of the counters. The digital form of the output lends itself readily to interfacing with a microcomputer which can be programmed to print out the ozone values directly. It is smaller, lighter and less expensive that the Dobson instrument, but there were a number of problems with the earlier manufactured versions, and it is possible that it is these which have led to a reluctance to accept it as the internationally recognized standard.

5. The changing interest in ozone measurements

The motivation for early measurements lay in the relationship between ozone production and stratospheric circulation. Ozone was observed to have an annual variation with a maximum amount in spring and a minimum in autumn, as shown in the record for Bracknell for the period 1969–85 (see Fig. 3). Following the work of Götz (1953) it was possible to obtain vertical profiles of ozone from measurements with an ozone spectrophotometer directed at the clear zenith sky, extending through sunrise or sunset. These vertical profiles were obtained in much greater detail when Brewer invented the first chemical ozone sondes (Brewer and Milford 1960). Chapman (1930) had given a theory of the photochemical production of ozone in a pure oxygen/nitrogen atmosphere, which for a long time seemed adequate, and the picture that ozone is generated at around the 10 mb level and transported to

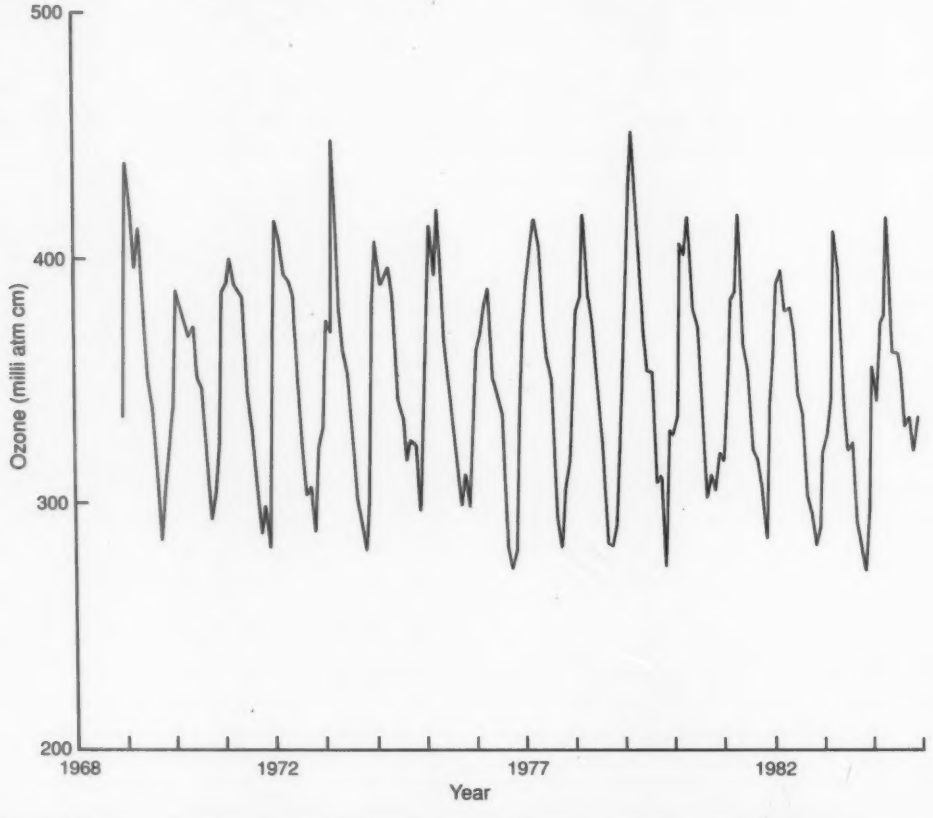

Figure 3. Monthly mean ozone column for Bracknell showing the annual cycle with a marked interannual variability.

lower levels and higher latitudes almost as an inert tracer is still valid, but in the late 1960s it began to be suspected that there were additional photochemical reactions at work in the lower stratosphere resulting in a destruction of ozone at rates greater than could be explained by the Chapman theory. Destruction by odd nitrogen species (NO and NO_2) odd hydrogen (OH and HO_2) and odd chlorine (Cl and ClO) were recognized as being important, and it was seen that the transport of chlorofluorocarbon species into the stratosphere would represent a threat to the ozone layer, which was now seen to be important in shielding the surface from short-wavelength ultraviolet radiation.

Attempts to confirm the importance of odd nitrogen species were made using calculations of the deposition of odd nitrogen in the stratosphere by nuclear weapon testing (Goldsmith *et al.* 1973), solar proton events, and the more extended deposition of oxides of nitrogen produced by the action of energetic particles in the upper atmosphere during the 11-year sunspot cycle. All these involved statistical analysis of as many observations as possible on the global scale. None proved really conclusive.

Detection of the effect of a slow build up of chlorine was expected to be even more difficult, even though statistical analysis of the total ozone column records suggested that it should be possible to detect a rate of change of about 1% per decade in a decade. It was expected that if the effect of ozone destruction were seen anywhere it would be in tropical latitudes, where insolation is greater and ozone variability less, and at high altitudes around 35–40 km. It was therefore a complete surprise that the first indication of a significant destruction of ozone by chlorine was seen in the records of one station, Halley Bay in Antarctica. Subsequent intensive studies showed that the ozone destruction was almost total in the lower stratosphere and that it was associated with the almost total isolation of the air in the southern polar vortex and the very low temperatures existing there at the end of the polar night.

The conditions prevailing in Antarctica in the Austral spring are not to be found elsewhere, but they illustrate the fact that there may yet be processes about which we are not yet aware and there is no substitute for continued monitoring of the total atmospheric ozone column with the greatest accuracy that can be achieved.

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Notes and news

The hundredth meeting of the Meteorological Committee

This is the record of a speech made by Dr John Houghton at the dinner following the 100th meeting of the Meteorological Committee on 16 October 1989.

I thought it would be interesting on this occasion of the 100th meeting of the Meteorological Committee to give some brief history of the Committee and its work and to present a few highlights gleaned from my perusal of the Committee's minutes over the years.

The Committee has had three manifestations during the last 122 years. Its first meeting was on 3 January 1867 at Burlington House, London; it was then a committee of the Royal Society and was chaired by the President. It met about once a fortnight and the £10 000 per annum budget of the Meteorological Office was under its control. Meetings on this regular basis continued for 10 years until 1877 in which year the Committee was renamed the Meteorological Council. The major difference between the Council and the Committee was that the members of the Council were paid for their work. Since they met once a fortnight and since they were in executive control of the Meteorological Office they felt that it was only reasonable that they should be paid for their services. Meetings of the Council continued until 1905 when, under the new Director of the Meteorological Office, Dr Napier Shaw (later Sir Napier Shaw), some different arrangements for the Committee were established.

The first meeting of the new Committee was on 20 May 1905 with the Director, Dr Napier Shaw, in the Chair. The Committee consisted of two members appointed by the Royal Society, the Hydrographer of the Navy, a representative of the Board of Trade, a representative of the Board of Agriculture and Fisheries, and a representative of the Treasury. They met four times per year and they were still in executive control of the finances of the Meteorological Office whose budget by then had risen to £19 000 per year. All cheques had to be signed by the Director and countersigned by a member of the Committee.

At the 97th Meeting of that manifestation of the Committee, on 15 October 1919, it was reported that the Meteorological Office was to come under the auspices of the Air Ministry. The Meteorological Committee remained much the same except that it was now chaired not by the Director but by the Controller General Civil Aviation. Amongst the representatives around the table were now two from the Air Ministry, one from the War Office and one from the Admiralty replacing the Hydrographer of the Navy in addition to those who were there before. The 114th meeting of the Committee was in 1922 when the Under Secretary of State for Air took over the chairmanship of the Committee from the Controller General Civil Aviation. At the 160th meeting on 4 July 1939, the last before the Second World War, there was an important discussion about the research work of the Office which resulted in the setting up of the Meteorological Research Committee. No more meetings occurred until the 161st meeting on 3 October 1946 when the Committee, still under the chairmanship of the Under Secretary for State for Air, was widened in its representation by even more government departments. During the years following the war the Committee met less frequently. At the 169th meeting on 15 June 1954 new television weather forecast presentations were described in which Meteorological Office personnel were taking part for the first time.

The year 1956 was an important year for the Office: in that year the move of the Office to Bracknell was agreed and approval for the purchase of the first Meteorological Office computer — the Ferranti 'Mercury', was given. Also in that year the last meeting of that second manifestation of the Committee occurred on the 18th October. At that meeting Mr Christopher Soames, the Secretary of State for Air, explained from the chair that the report of the Brabazon Committee had been received. This Committee had addressed the place of the Meteorological Office in government; it suggested a new structure for the Office and also a new structure for the Meteorological Committee. During that meeting Sir David Brunt said that he agreed that the Meteorological Committee as it was then constituted did not perform any useful purpose but he considered there was a need for an independent advisory body as a guarantee that the meteorological requirements of other important users were not subordinated to those of aviation.

So the third manifestation of the Meteorological Committee came into being. Its first meeting was on 17 October 1957 in the Historic Room 13, at the Air Ministry in Whitehall Gardens. It was a much smaller committee. Lord Hurcomb was in the chair, Sir Austin Anderson represented shipping, Sir David Brunt and Sir Charles Normand represented the scientific community and Colonel Stockford Sackville represented agriculture. Also present were Sir Graham Sutton, the Director-General of the Meteorological Office, Sir Folliot Sandford a Deputy Under Secretary from the Ministry of Defence, and Mr Crotch who was the Secretary. One of the matters discussed on that occasion concerned charges for forecasts. A recommendation of the Select Committee on Estimates was that a fee should be paid for forecasts supplied to the BBC and independent television companies proportionate to the fees paid by them for news items. The Committee's comment was that it was difficult to do this because the BBC and the TV companies do not pay fees for news items!

The 7th meeting of this new Committee was just 30 years ago in 1959 when Sir Graham Sutton was invited to speculate aloud about future developments in the Meteorological Office. Sir Graham said that he had recently embarked upon a new series of studies with his staff which he hoped would lead to an increasing use of electronic computers to relieve the human element of much of the present necessary drudgery. Development, he thought, would take about 5 years and might not be fully implemented for a decade, but he foresaw the time when the data flowing into the communications centre on punched tape could be directed immediately to an electronic computer which processed the observations to produce, on the face of a cathode-ray-tube, maps of the existing pressure distribution and also forecasts of the distribution of pressure up to 12 hours and perhaps even further ahead. This turned out to be an accurate forecast (even if somewhat optimistic on time-scale) of the development of numerical weather prediction in the Office. At the 9th meeting of the Committee in 1960, soon after the first artificial satellites were launched, a report was presented about the formation of the High Atmosphere Research Branch of the Office which was set up to respond to the new opportunities of satellite observations; 21 extra staff were taken on to form this new branch.

I became involved with the Committee around 1977 in my capacity as Chairman of the Meteorological Research Committee. I was interested to read the minutes of the 58th meeting in November 1977 when the Earl of Halsbury was in the chair — it is a special delight that he is able to be with us this evening. Dr Birks from BP and myself were the only other members of the Committee present on that occasion. Dr Mason, later of course Sir John Mason, Mr J.H. Nelson DUS(Air), Mr George Corby the Director of Services, Dr Ken Stewart the Director of Research, and Mr Colin Hughes the Secretary of the Office (who it is also good to have with us this evening) were also present. It was at that meeting that Sir John Mason put forward his view of the future development of the Office. He made two particular emphases which between them have increasingly dominated the work of the Office through the 1980s. First he addressed the development of commercial services saying that every effort should be made to expand and improve the Office's specialized services to industry, the Public Service and Commerce, thereby making a maximum contribution to the national economy. He pointed out that the Office had already become more commercially minded and cost-conscious;

it had increased its revenue from £2m in 1969–70 to an estimated £8.8m for the year 1977 an increase from 21% to 30% of gross expenditure. Of that £8.8m, £6.8m came from civil aviation and about £600 000 from the offshore industry. I was interested to read that at that meeting I commented on the Office's commercial activities saying that I believed that their expansion would be good for the Office and for the country because it would lead to greater benefit being realized from the work done by the Meteorological Office. The problem I saw was how this could be done without more freedom from the restrictions which inevitably accompany Civil Service activities. Not bad, I thought for a view from my Oxford ivory tower.

Sir John Mason's second point of emphasis at that meeting was the environment and the possible effects of man's activities on weather and climate which he predicted was likely to become of increasing political and economic importance. The Office should therefore give increased attention to understanding the physical basis of climate and to developing models to simulate and, perhaps, eventually predict climate changes both natural and man-made. This would almost certainly necessitate greater attention to the interaction between the oceans and the atmosphere and the development of joint atmosphere/ocean models.

As we moved into the 1980s the Committee itself became more involved with the Office's commercial activities. The Committee itself became larger, more customers were invited to join the committee and the interaction between the Office and the Committee has been an effective and useful way for the Office keeping in touch with its customers. Now as the Meteorological Office becomes an Executive Agency we enter a new era. There will be more freedom of action and more opportunities to serve the community in professional and commercial ways. I am sure that the Meteorological Committee will continue to provide, more than ever, valuable advice and guidance to the Office's Chief Executive.

No one would have predicted a hundred meetings ago the scale of the revolution which has been brought about by computers and by satellite observations. Nor would anyone have predicted the success of these tools and the scientific advances associated with them in improving the accuracy and the range of forecasts, and their availability to all sections of the community. If we project ourselves to the 200th meeting of this Committee we could, perhaps, imagine that meeting reflecting on the forecasts of climate made by the Office 50 years before. We can also, perhaps, rather dimly imagine them reflecting on the enormous increase in the development of technology and in the development of meteorological science and applications which had occurred during the first half of the twenty-first century. But, however they view those years I am sure they will be exciting and that future managers of the Meteorological Office will continue to look back with pleasure and appreciation at the advice, stimulation and gentle steer given by Meteorological Committee.

First All Africa International Symposium on Lightning, Harare, Zimbabwe, 30 April–4 May 1990

The symposium, which is being organized by the Zimbabwe Institution of Engineers (and co-sponsored by the UK Institution of Electrical Engineers), has already attracted more than 20 world-wide speakers.

The main objectives of the symposium are the encouragement of research, the exchange of information and investigations, recommendations and decisions on the possible establishment of a communications network to facilitate the exchange and dissemination of new knowledge and practices.

The topics to be covered will include structural protection, surge suppression, earthing, personnel and livestock protection, regulations, standards, codes of practice, techniques, equipment and industrial trends. It should be of particular interest to engineers, physicists and meteorologists, and over 200 international delegates are anticipated. Also, there will be technical visits to places of appropriate interest in and around Harare.

The Director-General of the Standards Association of Zimbabwe has described the forthcoming symposium as 'one of the most important technical meetings ever to be held in this country'.

Please contact the Editor, Meteorological Magazine has further details, or write direct to:

The Secretary
Symposium Organizing Committee
P.O.Box 1921
Harare, Zimbabwe
Africa.

British Hydrological Society

Allan Lambert, Special Projects Manager for Dwr Cymru (Welsh Water), is the new President of the British Hydrological Society for the next 2 years. The Society was formed in 1983 and now has over 600 members including a number of meteorologists with a special interest in hydrology. C. Collier, head of the Meteorological Office's Nowcasting and Satellite Applications Branch, is a member of the main committee. The Society aims to promote interest and scholarship in both the scientific and applied aspects of hydrology, and to foster the involvement of its members in international activities.

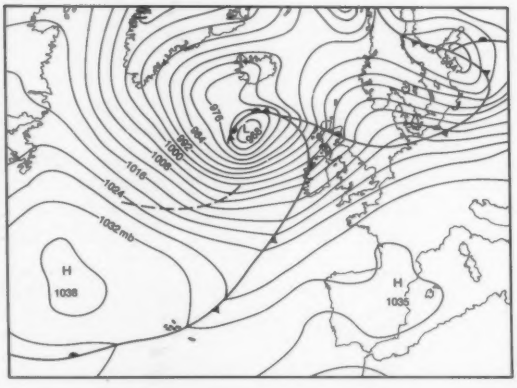
National and regional meetings are held on a wide range of hydrological topics, and a regular newsletter called *Circulation* is distributed to all members. If you are interested in knowing more about the Society and its activities contact C Collier, Room 140f, Meteorological Office, London Road, Bracknell, RG12 2SZ.

Satellite photograph — 16 January 1990 at 1200 UTC

This Meteosat infra-red image has been reprojected on to a polar-stereographic projection. The accompanying surface chart is on the same projection and covers the same area as the image. Note that the north-west corner of the image is missing; this is because this portion of the earth cannot be seen by Meteosat. Note also that the resolution of the basic satellite data is rather poor near this corner.

The main feature of interest is the cloud associated with the depression centred south of Iceland. The cold front and occlusion are readily apparent, although a rather amorphous cloud mass associated with the development and movement of the depression is more identifiable than anything particularly associated with the warm front. Indeed, at 0600 UTC the warm front had not been analysed as being connected to the cold front of the depression near the Baltic — instead, it had been trailed round into the Gulf of Genoa. There is some evidence on the image of a feature with this alignment, but it is an upper-level, frontolytic feature and not worthy of inclusion on the surface analysis. Similarly, there is evidence of a vortex in the western Mediterranean, but this again is an upper feature well documented on the 250 mb analysis (not shown).

Another feature of note is the area of enhanced convection south-west of the main depression, associated with a surface trough. The enhanced convection is also ahead of an upper trough, but neither the surface nor upper trough can separately explain the shape of the



area of enhanced convection. The following day, this feature became merged with the cloud associated with the occlusion, but at the time of this image they are quite distinct.

The image was reprojected using the Autosat-2 computer system which is at present under development in a number of Branches of the Meteorological Office. It will be used to process digital data from geostationary and polar-orbiter satellites, and promulgate them in appropriate projections to forecasters in the Central Forecasting Office, Bracknell, and also outstations and media customers.

R.W. Lunnon

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

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March 1990

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